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Journal of Systematic Innovation

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The works must be unpublished and refer to topics of electromagnetism, electrical distribution, sources innovation in electrical, engineering signal, amplification electrical, motor design science, materials in electrical power, plants management and distribution of electrical energies and other topics related to Engineering and Technology.

Presentation of the content

In the first article we present, *Artificial Intelligence Applications in the Supply Chain: A Narrative-Umbrella Review* by Silva-Leyva, Laura, Martínez-Contreras, Ulises, Woocay-Prieto, Arturo and Ronquillo-Salas, Carlos, with adscription in National Technological Institute of Mexico, Technological Institute of Ciudad Juarez, the next article we present, *Review on Adoption Models of Technology and their Barriers on Businesses* by Luthe-Rios, Rodolfo, Parres-Peredo, Alvaro and Calvario-Sánchez, Gabriela, with adscription in ITESO—The Jesuit University of Guadalajara, the next article we present, *Conceptual model of the impact of public policies on industrial supply chains* by Bocanegra-Villegas, Laura Valentina, Sánchez-Ramírez, Cuauhtemoc and Alor-Hernández, Giner, with adscription in Instituto Tecnológico de Orizaba, the last article we present, *Design and Implementation of a Hyperconverged Solution with Advanced Virtualization Technology* by Olvera-González, Edgar Alberto, Cerda-García, Jorge Alejandro, Viramontes-Reyna, José Luis and Alfaro-Castro, Jocelyn, with adscription in Univ Universidad Tecnológica de San Luis Potosí.



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Artificial Intelligence Applications in the Supply Chain: A Narrative-Umbrella Review



Aplicaciones de la Inteligencia Artificial en la Cadena de Suministro: Una Revisión Narrativa- Paraguas

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Abstract

Traditional statistical methods present limitations in the face of exponential data growth and the complexity of modern supply chains [SCs]. Artificial Intelligence [AI], with its ability to handle massive data, is gaining relevance. Therefore, it is interesting to understand, based on recent scientific publications, which AI algorithms are gaining importance, as well as their impact on the field. A search was conducted for systematic literature review articles on AI applications in SCs, identifying key areas and algorithms employed, their contributions, and potential future research. The selected articles were in English, had to contain the words "systematic review" in the title, and were due to be published between 2021 and 2025. They highlighted advances in various areas of the supply chain and identified opportunities in topics such as reverse logistics, environmental sustainability, returns automation, and the integration of AI with other technologies.

Resumen

Los métodos estadísticos tradicionales presentan limitaciones ante el crecimiento exponencial de los datos y la complejidad de las cadenas de suministro [SC] modernas, la Inteligencia Artificial [IA] al tener la capacidad de manejar datos masivos toma relevancia, por lo cual resulta interesante conocer según publicaciones científicas recientes cuáles son los algoritmos de IA que están tomando importancia, así como su impacto en el campo. Se realizó una búsqueda de artículos de revisiones sistemáticas de literatura de las aplicaciones de IA en la SC identificando las áreas clave y algoritmos empleados, sus aportaciones y posibles investigaciones futuras. Los artículos seleccionados son en el idioma inglés, debieron contener en el título las palabras "revisión sistemática", con fecha de publicación del 2021 al 2025. Destacaron avances en áreas diversas de la cadena e identificaron oportunidades en temas como logística inversa, sostenibilidad ambiental, automatización de devoluciones e integración de la IA con otras tecnologías.

Applications of the Artificial Intelligence in Supply Chain: A Narrative-Umbrella Review		
Objectives	Methodology	Contribution
Learn what algorithms and how artificial intelligence contribute to supply chain optimization.	Review of systematic literature reviews, selecting 10 relevant articles with publication periods from 2021 to 2025.	Identify the applications of Artificial Intelligence in the Supply Chain over the past three decades and identify potential gaps for future research.

Aplicaciones de la Inteligencia Artificial en la cadena de Suministro: Una Revisión Narrativa-Paraguas		
Objectives	Methodology	Contribution
Conocer que algoritmos y cómo la inteligencia artificial contribuye a la optimización de la cadena de suministro.	Revisión de revisiones sistemáticas de literatura, selección de 10 artículos relevantes con periodos de publicación del 2021 al 2025.	Identificar las aplicaciones de la Inteligencia Artificial en la Cadena de Suministro en las últimas tres décadas e identificar posibles lagunas para próximas investigaciones.

Artificial Intelligence, Sismatic Review, Supply Chain

Inteligencia artificial, revisión sistemática, cadena de suministro

Area: Promotion of frontier research and basic science in all fields of knowledge

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Introduction

The exponential growth in data volume, coupled with the complexity of modern supply chains, has revealed the limitations of classical statistical methods, which are not always adequate for making effective decisions or accurate forecasts. In this context, artificial intelligence [AI] algorithms have been implemented to improve and complement traditional statistical methods, providing more robust tools for the analysis and management of complex data. [Angos, M. et al., 2022; Nweje, U. and Taiwo, M., 2025]

This research focuses on a review of scientific publications that explores how artificial intelligence contributes to supply chain optimization. This document is relevant because, as a review of systematic literature reviews, it addresses important information from three decades by considering articles whose analysis material was from those time ranges. Relevant articles published from 2021 to date were selected, synthesized individually, and analyzed collectively to assess the contributions of AI algorithms at different stages of supply chain. It was observed that research focused on key areas: demand forecasting, inventory optimization, supplier selection, planning, and logistics, primarily. This study identifies gaps particularly in areas such as the application of AI for reverse logistics, environmental sustainability, automation in return processes, and integration of AI with other technologies. The review highlights the need for further research to address these areas to maximize the impact of artificial intelligence on the supply chain.

Methodology

This document is an umbrella review of review of reviews [Chambergo-Michilot, D., et al. 2021], an exploration of scientific publications of systematic literature reviews that explore how artificial intelligence contributes to supply chain optimization. The articles analyzed were published in English. The relevance of this document is that, by selecting systematic reviews, it addresses information from three decades by considering articles whose analysis material was from those time ranges. Ten important articles were selected, with publications period from 2021 to 2025, introducing artificial intelligence, systematic review, and supply chain [SC] as keywords.

These works were analyzed in terms of their methodological approaches and the impact achieved in different areas of supply chain. Each of them is summarized, and then a general conclusion is presented on the applications, as well as the gaps found in the literature for further research.

The first article, Artificial intelligence in supply chain and operations management: a multiple case study research, addresses how artificial intelligence [AI] has played a crucial role in supply chain management in recent years. Its applications cover various areas, such as demand forecasting, planning, inventory management, supplier selection, quality control in order receipt, manufacturing, maintenance, shipping, logistics optimization, picking, and warehouse management.

These applications have generated significant benefits, including reduced inventory days, lower costs, improve fault identification accuracy, resource optimization, increased customer satisfaction and product quality, reduce transportation time and cost, and advances in environmental sustainability. The integration of artificial intelligence methods with SCOR model [Plan, Source, Make, Deliver, and Return] is analyzed, highlighting the following aspects: In the area of *planning*, AI is applied to demand forecasting, demand planning, and inventory management. The techniques used include adaptive fuzzy neural inference system, seasonal models based on hybrid fuzzy intelligence, short-term memory [LSTM], and support vector regression [SVR]. However, machine learning [ML] methods have limitations, such as the need for large amounts of historical data and suboptimal performance in ambiguous situations.

To address these limitations, the use of hybrid models is recommended. In the area of *procurement*, which covers the issuance of purchase orders, delivery schedules, order receipt and validation, and the acceptance of supplier invoices, models based on fuzzy theory, multi-criteria decision models, genetic algorithms, and artificial neural networks [CNN], are used. For supplier selection, supervised learning, reinforcement learning, decision trees, and support vector machines [SVM] techniques applied.

The *manufacturing* process includes material conversion, maintenance, repair, recycling, remodeling, and manufacturing. The most relevant techniques include: simulation from predicting machinery failures, genetic algorithms for optimizing workflows, fuzzy logic [FL] and neural networks [NN] for planning customer needs, real-time data collection using the Internet of Things [IoT] and sensors, and the use of digital twins for process design, simulation, and validation. Specifically in *delivery*, which involves receiving, validating, preparing orders, packaging, and shipping, ANN and genetic algorithms are used to optimize logistics, warehouse management, and transport routes. Finally, reverse logistics, linked to the circular economy, benefits from the use of AI to automate and streamline the sorting of returns. Recent studies focus on models that optimize environmental factors related to returns.

In addition, the article also addresses the financial, organizational, strategic, technological, and legal barriers to the implementation of AI in the supply chain. Finally, the study suggests as future lines of research the application of AI in return processes, with an emphasis on the circular economy [Cannas, V. G., 2023]

The second article analyzed, Applications of Artificial Intelligence in Reverse Logistics: A Bibliometric and Network Analysis, reflects a comprehensive analysis of research conducted over the last three decades, identifying the most influential works, the main contributors, and the key connections between different studies in this field.

The findings highlight significant growth in the application of artificial intelligence [AI] within the field of machine learning [ML] in recent years. It mentions that several countries, including China, India, the United Kingdom, and the United States, have integrated cutting-edge AI-based technologies to optimize the flow in their reverse supply chains. These technologies have improved sustainability and efficiency by reducing waste within management systems.

Network analysis shows that researchers' attention has been focused primarily on issues related to recycling and waste management. To address these challenges, a variety of AI algorithms have been implemented. However, while remanufacturing has seen a significant increase in the use of AI, other critical areas still require greater attention in future research.

SA notable transition from the use of traditional machine learning algorithms to Deep learning [DL] was observed. This shift is due to the ability of DL algorithms to process data more quickly and operate efficiently in complex environments. In addition, hybrid models combining DL and ML algorithms have emerged, achieving promising results in addressing multifaceted problems. Some of these supervised learning algorithms used in reverse logistics are: linear regression [LR], support vector regression [SVR], random forest [RF], decision trees [DT], logistic regression [LR], regression trees [RT], backpropagation neural networks [BPNN], ensemble machine learning [EML], and inductive learning algorithms [ILA]. Unsupervised learning algorithms include: self-organizing map [SOM], K-means, and principal component analysis [PCA].

Deep learning [DL] requires input data for the algorithm to classify into three categories: prediction, classification, and estimation.

The document mentions multiple Deep learning algorithms with applications in reverse logistics: convolutional neural networks [CNN], You Only Look Once [YOLO], artificial neural networks [ANN], recurrent neural networks [RNN], multilayer perceptrons [MLP], long short-term memory [LSTM], and Deep belief networks [DBN].

AI continues to evolve, and in the area of reverse logistics, it has been applied in multiple ways: predicting manufactured products, classifying and identifying waste, return rates, predicting recycling, forecasting waste, sustainable transportation, storage and packaging, waste collection in a smart environment, demand forecasting, product return, rate predictions, cost forecasting, grouping discarded material for reuse, examining multiple factor trends, and sorting recyclable materials, to name a few.

Predictive analytics will play an essential role in improving processes such as remanufacturing by optimizing product returns within the supply chain. For example, using historical data to accurately predict return volumes will maximize the value of returning products, promoting a more sustainable and efficient economy.

In summary, AI has improved reverse logistics management and has been applied to remanufacturing, but it also shows that the processes of product reuse, refurbishment, and return lag behind in the application of AI. As technological advances continue to redefine the limits of what is possible, the opportunities to improve supply chain management through AI are extensive.

This study provides valuable information for harnessing the potential of artificial intelligence in the future to solve critical challenges in global sustainability and efficiency [Bhowmik, O. et al., 2024].

The third article, Systematic literature review on artificial intelligence applications in supply chain demand forecasting, provides a concise summary of systematic literature review conducted on the applications of artificial intelligence [AI] particularly machine learning [ML] and deep learning [DL] in supply chain demand forecasting, comparing them with traditional forecasting techniques. The authors followed by PRISMA [Preferred Reporting Items for Systematic Reviews and Meta-Analyses] guidelines to conduct a comprehensive search of the relevant literature. The 65 selected articles were subjected to an in-depth analysis to evaluate the performance of AI-driven models compared to traditional forecasting techniques.

This analysis included examining the advantages of AI models, the scalability and responsiveness of forecasting to real-time data, such as greater accuracy, scalability, and responsiveness of real-time forecasts, as well as identifying the challenges faced in implementation. The review highlights that AI-driven models, particularly those using machine learning [ML] and deep learning [DL], significantly outperform traditional forecasting techniques by improving forecast accuracy. It also found that AI applications are beneficial in retail, manufacturing, and trade. The review also points to several challenges that hinder the widespread adoption of AI in demand forecasting, including issues related to data quality, the complexity of AI models, and high implementation costs, which may limit organizations willingness to adopt these advanced technologies.

It suggests areas for future research, focusing particularly on improving data management practices, developing more interpretable AI models, as this would facilitate wider implementation of AI, leading to better forecasting and decision-making, and exploring ways to reduce high implementation costs [Saha, R., et al., 2024].

The fourth article is “The role of Artificial Intelligence in Supply Chain Management: A Systematic Literature Review”. IT highlights that companies, to remain competitive and efficient, must integrate advanced technology, particularly artificial intelligence. The article conducted a systematic literature review, analyzing papers published in peer-reviewed journals from major databases such as Scopus and Web of Science.

The analysis included an assessment of the frequency of the literature, focusing on years of publication, contributions from leading journals and publishers, and the methodologies used in the studies.

It was found that AI applications in the supply chain include demand forecasting, inventory level optimization, logistics operations efficiency, and the identification and management of risks within the supply chain. The use of AI in these areas allows better-informed decisions, minimized forecasting errors, and improves the overall efficiency of the chain.

For future research in the field of AI and supply chain management, it recommends investigating advances in machine learning, deep learning, and other AI methodologies that have not yet been fully integrated to further improve processes in the supply chain, as well as integrating AI with other advanced technologies such as the Internet of Things [IoT], blockchain, and Big Data. It also recommends conducting longitudinal and sectoral studies, as well as examining the ethical and social implications of Ai in SCs. The paper highlights the need to develop standardized performance metrics to evaluate the effectiveness of Ai applications in SC management. The paper concludes that the integration of AI technologies is fundamentally transforming supply chain management, leading to greater efficiency, agility, and resilience in operations, and improving decision-making processes [Logožar, K., 2024].

The objective of the fifth article, *Advancing supply chain management through artificial intelligence: a systematic literature review*, is to evaluate how artificial intelligence [AI] influences supply chain management [SCM] by seeking to understand how AI can improve SCM practices and what challenges exist in its implementation. The study employs a systematic literature review, which is structured in a five-step process. It analyzes academic publications from 2000 to 2024, using various databases to ensure a comprehensive review, identifying a total of 426 articles relevant to its analysis.

The study highlights that AI techniques have considerable potential to improve efficiency, accuracy, and decision-making processes within SCM. It also identifies several barriers that hinder the wider implementation of AI in SCM. These barriers include financial constraints, organizational issues, strategic misalignments, technological limitations, and legal barriers.

The paper suggests investing in infrastructure, developing employee skills, and implementing effective management practices, as well as exploring new AI applications, conducting longitudinal studies, adopting interdisciplinary approaches, documenting practical implementations, and addressing ethical and legal considerations [Younesse, O. et al., 2025].

The sixth article, *Examining the integration of artificial intelligence in supply chain management from Industry 4.0 to 6.0: a systematic literature review*, provides summary of research conducted on the integration of Artificial Intelligence [AI] into supply chain management [SCM] as industries transition from Industry 4.0 [“smart” and connected production systems that are designed to detect, predict, and interact with the physical world in order to make decisions that support real-time production, [WEF, 2022]] to Industry 6.0 [merging human-centered automation, hyperconnectivity, and cognitive manufacturing, driven by advances in artificial intelligence, quantum computing, and edge computing [Roshid, M., et al., 2025]].

The research uses the PRISMA framework for systematic review of literature, analyzing literature published between 2010 and 2023.

A comprehensive search was conducted in multiple databases, including Web of Science, Scopus, IEEE Xplore, Google Scholar, and Science Direct. The review process involved rigorous eligibility screening and thematic analysis using Atlas-ti software to identify key themes related to Ai integration in SCM. Ai integration significantly enhances SCM by improving demand forecasting, inventory management, and overall decision-making capabilities.

The transition to Industry 5.0 emphasizes huma-Ai collaboration, leading to better personalization and problem solving. Additionally, Ai technologies contribute to sustainability by optimizing resource use and minimizing environmental impacts. However, challenges such as cybersecurity risks and workforce skill gaps must be addressed to fully leverage the potential of AI. The integration of Ai into SCM not only increases operational efficiency and sustainability but also improves resilience to disruptions. The study highlights the importance of balancing technological advances with sustainable, human-centered practices.

The findings of the document highlight several significant results, such as improved demand forecasting helping to optimize inventory levels and improving decision making processes. The transition to Industry 5.0 emphasizes the importance of human-AI collaboration, leading to more personalized solutions, problem solving, contributions to sustainability, optimization of resource utilization, and reduction of environmental impacts.

The study also identifies several challenges that must be addressed for effective Ai integration, including cybersecurity risks and workforce skill gaps. The study concludes that a balanced approach is necessary for successful Ai integration in SCM. This approach must combine technological advances with sustainable, human-centered practices, ensuring that the benefits of AI are realized while mitigating the associated risks [Samuels, A., 2025]. Artificial Intelligence [AI] is transforming supply chain management [SCM] by improving efficiency, reducing costs, and optimizing resources, as mentioned in the seventh article, *Artificial Intelligence in Supply Chain Management: A Systematic Literature Review and Guidelines for future research*.

They show how the most prevalent techniques, artificial neural networks [ANN], fuzzy logic [FL], and genetic algorithms [GA], offer promising results, but their combination could maximize benefits and minimize risks. This study addresses the lack of systematic reviews by identifying gaps in literature and exploring practical applications. Emerging topics such as sustainability, big data, and automation are also highlighted. It concludes that AI is key in SCM, but future research should consider its impact on organizations of various sizes.

Articles were selected from Elsevier Scopus database, searching by title, abstract, and article keywords to identify peer-reviewed systematic reviews in English published from 2018 to mid-2022. Thirty-four documents were analyzed.

Three Ai techniques applied to SCM were identified: ANNs, genetic algorithms, and FL. ANNs are mainly applied to marketing, sales forecasting, and customer segmentation. Genetic algorithms [GA] allow for parameter optimization and can also be extended to multi-objective optimization [MOO]. Fuzzy logic allows for addressing uncertainty, unpredictability, difficult to-formulate systems, and ambiguity of information, making it an excellent technique for working with qualitative information.

Due to the growing volume of data, big data analytics have proven crucial in addressing changes such as the IT revolution, customers awareness, and globalization. The use of big data analytics [BDA] in conjunction with artificial intelligence was defined as the best solution, as it allows companies to extract useful information from large amounts of data and use it to address SCM issues. BDA is considered the best way to combat market competitiveness. Finally, automation, which can be divided into three different capabilities: “process automation”, “operational automation” and “tactical automation”.

In terms of future research, it is suggested to examine how the application of Ai techniques might differ between organizations of different sizes: research is also proposed to explore the risk of using AI technologies in SC [Ferreira, B. & Reis, J., 2023].

Article number eight, Artificial intelligence in supply chain management: A systematic literature review, identifies the contributions of artificial intelligence [AI] to supply chain management [SCM], addressing four aspects: outstanding AI techniques, as well as those that have potential for applications in SCM: subfields enhanced through AI in SCM: and subfields susceptible to development through AI.

Using a specific set of inclusion and exclusion criteria to identify and examine the literature, the key words from Stock and Boyers's [2009] definition of SCM were used: supply chain, marketing, production, and logistics, combined with “artificial intelligence”.

Only peer-reviewed conference and journal articles were evaluated. From 2008 to 2018. The databases used were Wiley Online Library, ScienceDirect, Emerald Insight, Taylor & Francis, and JSTOR.

Of the 64 articles analyzed, 14 contribute to the area of marketing, 6 to logistics, 23 to production, and 21 to the general field of supply chain, five focus on demand forecasting, proposing the use of artificial neural networks [ANN], fuzzy inference systems, and support vector machine to manage fuzzy demand, develop a model for customer segmentation to improve inventory, and accurately forecast demand. Two articles focus on supplier selection, with the application of fuzzy Bayesian supplier selection and neuro-fuzzy supplier selection. Simulation, the use of Radio Frequency Identification [RFID] integrated with Information Technologies [IT], as well as the Internet of Things [IO] applied to the monitoring of risks and inventory replenishment problems. For marketing, the use of ANN, agent-based systems [ABS], genetic algorithms [GA], k-mean clustering, support vector data, multi-agent systems [MASs], and neural decision trees [NTD] stand out, with the results of these applications including sales forecasting, pricing models, market segmentation, and predicting consumer decisions, among others.

In the field of logistics, the use of heuristic methods, intelligent systems, and autonomous agents is mentioned. AI and RFID techniques are used in the operation and management of cargo containers and batch problems.

In the field of production, GA, ANN, NTD, data mining, FL, Gaussian models, and case-based reasoning [CBR] are used for production forecasting, production fault detection, production planning and scheduling, quality improvement and control, product line optimization, rapid prototyping, and manufacturing.

In conclusion, in any of the fields, the most widely used Ai technique was ANN, and specifically for SC, the second most widely used technique was FL and modeling. It is concluded that many studies focus on the design and creation of models, but only a few evaluate their application or use. This conclusion suggests the use of real data to test the proposal. It also mentions that improving the use of AI in SCM requires well-structured problems and the use of appropriate software. Another recommendation is the application of agent-based systems [ABS] for risk or disaster management in the chain [Toorajipour, R. et al., 2021].

The ninth paper, Artificial intelligence applied to supply chain operations management: a systematic literature review, emphasizes that AI is crucial for minimizing operational uncertainty and improving performance in supply chain management [*SCM]. Big data analytics [BDA] is an important area within AI; both are transforming supply chains.

The systematic review for the paper covers the literature on Ai applications in SCM from 2000 to 2020 using a meta-synthesis methodology.

The paper addresses the main methodologies used in the Ai SCM literature and includes qualitative, quantitative, and mixed-method approaches. It identifies the areas in which it is mainly applied, namely demand forecasting, inventory management, logistics optimization, and supplier selection. It also addresses the most frequently used AI models, covering machine algorithms, neural networks, and optimization techniques, including BDA.

It identifies the need for more empirical studies and exploration of new AI technologies and their applications in supply chains. These include investigating the long-term impacts of AI on supply chain resilience, exploring the ethical implications of AI in SCM, and addressing issues related to data privacy, algorithmic bias, and the impact on employment in the industry.

It also involves developing frameworks for integrating AI technologies into existing supply chain processes. Encouraging interdisciplinary research that combines knowledge from various fields, such as operation management, information systems, and data science. This interdisciplinary approach can lead to more comprehensive solutions and innovations in SCM.

This forward-looking perspective aims to guide research in improving the overall understanding of the role of AI in SCM and addressing the challenges and opportunities it presents [Dayrell, M. & Fontes, O., 2023].

The tenth article, Applications of artificial intelligence and machine learning within supply chains: systematic review and future research directions, the purpose of this research is to examine how artificial intelligence [AI] and machine learning [ML] techniques are currently being applied in supply chain management, with the aim of identifying their main advancements, benefits, and potential directions for future research.

Through a systematic literature review conducted across major databases such as Web of Science, Scopus, and Google Scholar, a total of 388 publications were analyzed, of which 50 were selected for their relevance in directly linking AI and ML to supply chain management. The findings reveal that these technologies have significant potential to enhance operational efficiency, improve responsiveness, and provide competitive advantages to organizations. Among the most notable outcomes are the reduction of the bullwhip effect and the optimization of logistics networks. However, the authors agree that the full potential of AI and ML has not yet been fully realized.

The study further suggests that their application could be strengthened through integration with emerging technologies such as big data and robotics. It also emphasizes the importance of continuing to explore and deepen the use of these tools within supply chain management, as there remain numerous promising approaches that have yet to be investigated [Younis, H., et al., 2021]

Table 1 presents a resume for articles.

Box 1

Table 1

Summary by article

YEAR OF PUBLICATION	ARTICLE	REVIEW METHODOLOGY	APPLICATIONS	FUTURE RESEARCH
2023	Artificial intelligence in supply chain and operations management : a multiple case study research	Artificial intelligence methods with Score model	Demand forecasting and planning Inventory management Supplier selection Supplier selection Issuing receiving and validating orders failure prediction Warehouse and transport route management	IA in Return Processes with an emphasis on the circular economy
2024	Application of artificial intelligence in reverse logistics: A bibliometric and network analysis	Bibliometric and network analysis. Sources: journals, conferences, reviews, and book chapters. Scopus database, Google Scholar 1990-2023 Information from journals, HistCite, Tableau, and R Studio	Waste classification and identification demand forecast	AI in refurbishment, reuse, and product return management
2024	Systematic literature review on artificial intelligence applications in supply chain demand forecasting.	PRISMA guidelines	Inventory management, production scheduling, and overall operational efficiency	Develop more interpretable AI models. Explore ways to reduce the high costs of implementation with AI technologies
2024	The role of Artificial Intelligence in Supply Chain Management: A systematic Literature Review	Systematic literature review, analyzing Works published in Scopus and Web of Science. Frequency analysis, contribution analysis, methodological evaluation, and content analysis	Demand forecasting, inventory management, logistics operation, risk management	Investigate advances in ML, DL, and other AI methodologies not yet integrated into supply chain practices Examine the integration of AI with other advanced technologies, such as the Internet of Things [IoT], blockchain, and big data analytics. Research data privacy, job displacement, and the overall impact of AI on workforce dynamics within the SC.
2025	Advancing supply chain management through artificial intelligence: a systematic literature	Five-step process structure, publications from 2000-2024	Improves efficiency, accuracy, and decision-making processes	Explore new AI applications, conduct longitudinal studies, adopt interdisciplinary approaches, document practical implementations, and address ethical and legal considerations
	Examining the integration	PRISMA Framework Publications from 2010 to	Mejora la previsión de la demanda, la	Combine technological advances with

2025	of artificial intelligence in supply chain management from Industry 4.0 to 6.0: a systematic literature review	2023 databases, Web of Science, Scopus, IEEE Xplore, Google Scholar, and ScienceDirect Atlas-ti software to identify key topics related to the integration of AI in SCM	administración de inventario y la toma de decisiones	sustainable, human-centered practices
2023	Artificial intelligence in supply chain management : a systematic literature review and guidelines for future research	PRISMA and content analysis Elsevier Scopus database, 34 articles	Marketing, sales forecasting, and customer segmentation Parameter optimization	Exploring the risks of using AI technologies in SC Investigate how AI techniques may differ between organization of different sizes.
2021	Artificial intelligence in supply chain management : A systematic literature review,	Wiley Online Library, ScienceDirect, Emerald Insight, Taylor & Francis and JSTOR Papers from 2008 to 2018 only peer-reviewed journal and conference papers were considered for the review 64 articles	Risks, Inventory, value chain, planning, maintenance, demand forecasting, supplier selection, supply chain design, management, chain integration planning, sustainability	Use of real data to test proposed models. Design of well-structured problems and use appropriate software.
2023	Artificial intelligence applied to supply chain operations management : a systematic literature review.	Meta-synthesis of articles from 2000 to 2020.	Demand forecasting, inventory management, logistics optimization, and supplier selection.	Long-term impact of AI on SC resilience Ethical implications Data privacy Impact on employment in the industry Interdisciplinary research Exploration of new technologies and their applications in SC
2021	Applications of artificial intelligence and machine learning within supply chains: systematic review and future research directions	Databases used: Web of Science, Scopus and Google Scholar 50 articles reviewed	Reduction of the bullwhip effect	Research on Big Data and Robotics in SC

Source: Own elaboration

Results

Table 1 provides a concise overview of the methodology, applications, and future lines of research in supply chain.

Conclusions

AI is transforming the supply chain, enabling problems to be solved more accurately, faster, and with more information, which is why it has multiple applications.

The articles analyzed provide an understanding of the variety of algorithms used in the field of AI and highlight the diversity of applications of this technology throughout the supply chain, including demand forecasting, inventory optimization, predictive maintenance, risk management, and supplier selection, to name just a few.

These studies also identify gaps in current research and potential opportunities for future inquiries in this field. Among the many suggestions for future research are AI in return processes with an emphasis on the circular economy, AI for returns management, exploring ways to reduce the high costs of implementation, examining the integration of AI with other technologies, data privacy, risk exploration, combining technological advances with sustainable practices, resilience in the SC, and research on big data and robotics.

Although AI and ML are adding value to supply chains, some researchers believe that these technologies are not fully exploited, suggesting that there are still many tools and techniques that could improve the overall value of supply chains [Younis, H., et al., 2021]. The adoption of AI provides competitive advantages and contributes to a more sustainable future, hence the importance of embracing it. [FEM, 2022, Hinojosa, R. O., 2025].

Declarations

Conflict of interest

No conflict of interest is declared; there no financial or personal interests that could have influenced the content of this article.

Author contribution

Martínez, Ulises y Woocay, Arturo: contributed with suggestions for articles to review and research.

Ronquillo, Carlos: contributed with suggestions for articles, research, and as corresponding author.

Silva, Laura: contributed with the idea, research and narrative.

Availability of data and materials

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Abbreviations

ABS	Agent-based systems
AI [IA]	Artificial Intelligence
ANN	Artificial Neural Network
BDA	Big Data Analysis
BPNN	Backpropagation neural network
DBN	Deep Believe Network
CBR	Case-Based Reasoning
CNN	Convolutional Neural Network
DL	Deep Learning
DT	Decision Trees
EML	Ensemble Machine Learning
FL	Fuzzy Logic
GA	Genetic Algorithm
ILA	Inductive Learning Algorithm
IoT	Internet of Things
K-NN	k-Nearest Neighbors
LR	Logistic Regression
LSTM	Long Short-Term Memory
ML	Machine Learning
MLP	Multy Layer Perceptron
MOO	Multi-objective optimization
NB	Naïve Bayes
NTD	Neural Decision Tree
PCA	Principal component analysis
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RF	Random Forest
RFID	Radio Frequency Identification
RL	Lineal Regression
RNN	Recurrent Neural Network
RT	Regression Tree
SC	Supply Chain
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SOM	Self-Organizing Map
SVM	Machine Support Vector
SVR	Support Vector Regression
TICS	Information Technologies
YOLO	You Only Look Once

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Review on Adoption Models of Technology and their Barriers on Businesses

Revisión sobre los modelos de adopción de tecnología y sus barreras en las empresas

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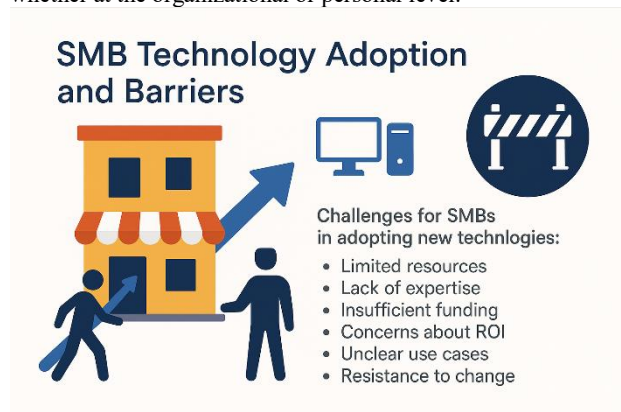
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Abstract

Small and medium sized businesses [SMBs] play a crucial role in emerging economies as they serve as the primary employer and source of development for individuals and society. SMBs face significant challenges in their development, and few manage to survive beyond 10 years to be considered established businesses. Typically, information technologies do not act as strategic partners for SMBs that support their growth and address business problems; they often remain completely separate from the business. Several reasons contribute to the lack of adoption of these technologies, including limited resources, lack of technical expertise, insufficient funding, concerns about return on investment, unclear use cases, and resistance to change. This research report aims to identify models that study how SMBs adopt new technologies and the barriers faced in this process, whether at the organizational or personal level.



Technology adoption models, Technology adoption barriers, small medium business [SMB], Small medium enterprises [SME]

Resumen

Las pequeñas y medianas empresas [PYMES] desempeñan un papel crucial en las economías emergentes, ya que son el principal empleador y fuente de desarrollo para las personas y la sociedad. Las PYMES enfrentan retos significativos en su desarrollo y son pocas las que logran permanecer más de 10 años para ser consideradas empresas establecidas. Por lo general, las tecnologías de la información no son un socio estratégico de las empresas que apoyen su crecimiento y resuelvan problemas de negocio, usualmente son totalmente separables del negocio. Entre las razones por las que estas tecnologías no son adoptadas están recursos limitados, falta de experiencia técnica, falta de recursos y preocupación sobre el retorno de inversión, falta de casos de uso claros y resistencia al cambio. Este reporte de investigación tiene como objetivo identificar modelos que estudien cómo las PYMES adoptan nuevas tecnologías y las barreras que enfrentan en este proceso, ya sea a nivel organizacional o personal.



Modelos de adopción de tecnología, Barreras de adopción de tecnología, Pequeñas y medianas empresas [PYME]

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

The Organisation for Economic Co-operation and Development [OECD] reports that Latin America and the Caribbean [LAC] faces a challenging macroeconomic landscape due to political transitions, socioeconomic situations, the COVID-19 pandemic, and the effects of Russia's aggression against Ukraine. Small and medium-sized businesses [SMBs] play a crucial role in LAC, constituting 99.5% of businesses and contributing approximately 60% of formal productive employment [*Índice de Políticas para PyMEs, 2024*].

The National Institute of Statistics and Geography [INEGI] [*Estudio sobre la Demografía de los Negocios (EDN) 2023, 2024*] reports that, in Mexico in 2019, 99.8% of the establishments in the country are micro, small, or medium-sized businesses. According to the Institute of Economic Research of Guadalajara [IEEG] [*Guadalajara, 2022*], SMBs represent approximately 70% of the GDP of the state of Jalisco.

Policies related to SMBs represent a critical area because, in most countries, the highest concentration of economic activity occurs within this sector. Additionally, these businesses possess significant potential to create jobs and foster shared prosperity on a large scale [Tewari et al., 2013].

Although the adoption of new technology creates opportunities in business by enabling what was previously impossible, it can also generate problems by disrupting the routines and processes that employees, such as system users, are accustomed to in conducting their tasks. Adopted technology is unpredictable and can negatively impact an organization, leading to situations where newly implemented systems may not be used effectively [Dube et al., 2020].

Many challenges continue to hinder the adoption of digital technologies by SMBs in developing economies. SMBs operating in the informal sector within emerging markets and developing economies [EMDEs] face similar obstacles that inhibit their ability to adopt advanced technologies and innovations necessary for improving business operations and re-engineering processes.

The technologies and technical innovations that appear novel in EMDEs have long been established in advanced economies. Most cutting-edge technologies, such as cloud computing, big data, and predictive analytics, which can significantly improve operations and strategic decision-making, have yet to gain traction in many EMDEs. Furthermore, SMBs largely underutilize disruptive computing technologies, data analytics, and the Internet of Things [IoT], despite these technologies' potential to help them develop innovative business models, reduce operational costs, strengthen competitive advantages, and advance digital transformation.

The limited adoption of digital technologies in EMDEs explains many businesses' significant challenges during the SARS-CoV-2 outbreak and the lockdowns imposed to contain the COVID-19 pandemic. To thrive in the "new normal" brought about by COVID-19 and intense global competition, successful adoption of advanced technologies becomes essential for these enterprises [Ikpe Justice Akpan & Adebisi, 2022].

One of the key recommendations from the OECD that applies generally to the LAC region is to promote the digitalization of SMBs through enhanced national digital strategies with well-defined implementation plans, emphasizing the development of broadband policies focused on SMBs to address specific challenges [*Índice de Políticas para PyMEs, 2024*].

Challenges facing SMBs in the LAC region exist as reported: in Peru, insufficient environmental education, a lack of business incentives, and limited IT resources constrain growth [Madrid et al., 2025]. In Ecuador, universities adopt cloud computing based on a combination of technological, organizational, economic, and security factors [Mero-Terán et al., 2025]. In Colombia, significant barriers to digital technology adoption include limited financial resources, resistance to organizational change, employees' lack of digital skills, and a technological infrastructure gap, particularly in rural areas [Linares et al., 2024].

This research report aims at identifying models that examine how SMBs adopt new technologies and the barriers faced in this process, considering both the organizational and personal level.

The present document is structured as follows. Section II introduces the theories, frameworks and models that examine technology adoption, and Section III presents the adoption barriers that businesses encounter when adopting new technologies. Finally Section IV presents the conclusions.

II. Theories, Frameworks and Models of Technology Adoption

According to Dube et al [Dube et al., 2020], technology adoption defines the initial use or acceptance of a new technology or system. Numerous theories, frameworks, and models for technology adoption identify, predict, and describe the variables that affect adoption behavior in both individuals and organizations. These factors typically fall into three categories: 1] Organizational factors, 2] Technological factors, and 3] Environmental factors [Hendricks & Mwapwele, 2024].

Some of this theories and models include: 1] technology acceptance model [TAM], 2] innovation diffusion theory [IDT], 3] the theory of reasoned action [TRA], 4] theory of planned behavior [TPB], 5] technology organization environment [TOE], and 6] unified theory of acceptance and use of technology [UTAUT]. Dube et al [Dube et al., 2020] finds that TAM, UTAUT, and TOE extensively apply to technology adoption at the organizational level. Many studies identify TAM as an effective leading model; it provides both theoretical and practical insights and serves as the most widely used framework by information systems [IS] researchers for predicting various users' acceptance of information technology [IT] in organizational contexts. TAM acts as a primary model for examining technology adoption at the organizational level.

Although UTAUT is designed to foresee technology adoption at the individual level, few studies explore its application at the organizational level. The TOE framework develops a theoretical perspective on technology adoption and the implementation of technological innovations. It offers a holistic view by considering both internal and external influences on technology adoption.

The IDT theories align with the organizational context and expertise found in the TOE framework.

A. Technology Acceptance Model [TAM]

Due to the lack of user acceptance of information systems, Davis develops the technology acceptance model [TAM] theoretical framework in 1986 [Davis et al., 1989]. This model predicts and explains how users accept and utilize new technologies. TAM builds on the theories of reasoned action [TRA] and planned behavior, distinguishing between principles, attitudes, beliefs, and intentions.

TAM calculates the perceived adoption of future behavior rather than actual behavior. The model focuses on two key constructs: perceived usefulness [PU] and perceived ease of use [PEU], as illustrated in Fig. 1. TAM identifies two factors that serve as determinants of behavioral intention [BI] to use new technology, which subsequently drives usage behavior [UB].

a) Perceived Usefulness [PU]. This construct refers to the degree to which a user believes that using a technology enhances their job performance. Essentially, when users perceive that a technology can help them achieve their goals more efficiently, they are more likely to adopt it.

b) Perceived Ease of Use [PEU]. This construct relates to the extent to which a user believes that using the technology requires minimal effort. When users perceive a technology as easy to use, it increases the likelihood of its acceptance.

Dube et al [Dube et al., 2020] points out that TAM has limitations, such as neglecting social influences and failing to account for external factors that might affect technology adoption.

B. Technology Organization Environment [TOE] framework

The technology organization environment [TOE] framework serves as a theoretical model that Tornatzky and Fleischer develop in 1990 [Tornatzky & Fleischer, 1990], aiming to understand the factors influencing the adoption and implementation of technological innovations within organizations.

According to Dube et al [Dube et al., 2020], the inclusion of organizational, technological, and environmental variables makes TOE advantageous compared to other models used to study technology adoption. This framework focuses on higher-level attributes rather than detailed behaviors of individuals within the organization. The three critical contexts that affect technology adoption are: organization, technology, and environment [Dube et al., 2020].

Dube et al [Dube et al., 2020] also mentions that the TOE framework has limitations because it does not represent an integrated theoretical framework or a well-established theory. Its broad nature can make it challenging to apply in specific contexts.

C. *Unified Theory of Acceptance and Use of Technology [UTAUT]*

The unified theory of acceptance and use of technology [UTAUT] serves as a comprehensive framework that Venkatesh et al. developed in 2003 [Venkatesh et al., 2003] to explain the factors influencing technology acceptance and usage.

Dube et al [Dube et al., 2020] notes that UTAUT enables analysis of users' intent to use an IS and the behaviors resulting from using an IS or technology. UTAUT categorizes four vital factors [Dube et al., 2020]: performance expectancy, effort expectancy, social influence, and facilitating conditions. It also identifies four moderators that can influence the relationships between these vital factors: age, gender, experience, and voluntarism. These moderators help explain variations in technology acceptance across different demographic groups and contexts.

Dube et al [Dube et al., 2020] finds limitations and challenges within UTAUT, noting that although many studies cite this model, only a small number actually utilize it. Furthermore, the subjective measures currently in use remain unvalidated, leaving their relationship to technology or system usage often unknown.

D. *Integrating Models*

Dube et al [Dube et al., 2020] concludes that integrating models to develop a new framework proves valuable, particularly when considering the limitations of various technology adoption models and theories.

As an example of model integration, Tongsuksai [Tongsuksai et al., 2023] combines the organizational [TOE] and individual [UTAUT] models, allowing for the inclusion of dimensions that each model does not cover.

III. Adoption Barriers

Adopting new technologies in small and medium-sized businesses [SMBs] offers numerous benefits, such as enhancing operational capabilities; however, companies face multiple challenges in this adoption process. In some cases, companies need to radically change individual mindsets, organizational design, and corporate strategic vision while implementing modern technologies that support new business objectives and customer requirements [Omrani et al., 2024].

SMBs encounter significant challenges when implementing new technologies like AI, big data, or IoT. While larger companies often prepare better for adopting these technologies due to their greater resources and capabilities, many SMBs struggle to do the same [Omrani et al., 2024].

Senna [Senna et al., 2022] studies the barriers to the adoption and implementation of Industry 4.0 technologies in the manufacturing sector. He identifies fourteen barriers to adopting these technologies, categorizing them according to the criteria of the TOE framework. Omrani [Omrani et al., 2024] identifies and analyzes factors that determine the adoption of digital technologies in SMBs, concluding that organizational drivers predominantly influence adoption over technological and environmental factors.

Various authors [Dube et al., 2020; *Examining the context-specific reasons and adoption of artificial intelligence-based voice assistants: A behavioural reasoning theory approach - Anayat - 2023 - International Journal of Consumer Studies - Wiley Online Library*, s/f; Hendricks & Mwapwele, 2024; Kinkel et al., 2022; Omrani et al., 2024; Senna et al., 2022; Tongsuksai et al., 2023] identify barriers to technology adoption in SMBs according to the TOE framework.

This framework proposes that the decision to adopt an innovation is based on technological, organizational, or environmental contexts.

The relationship between these barriers and the TOE contexts are shown in Table I which is described below.

A. Organization

The organizational context refers to internal factors that serve as descriptive measures of the organization [Senna et al., 2022]. These measures include size, scope, organizational structure, managerial hierarchy, and financial resources [Dube et al., 2020]. The attributes within this context determine how an organization adapts to new technologies and its readiness for adoption. This context is crucial for understanding how organizational characteristics influence technology decisions.

B. Technology

The technology context encompasses the characteristics of the technology itself, both within the organization and those related to communications and information exchange outside of it [Senna et al., 2022]. It addresses the technologies currently in use by the organization as well as new technologies that may be relevant for adoption. This context significantly impacts how technological adoption occurs within an organization.

C. Environment

The environmental context refers to external factors that influence an organization's technology adoption decisions, such as the location where the organization operates and conducts its business, as well as relationships with clients and suppliers [Senna et al., 2022]. This context includes outside elements affecting the business, such as government incentives and competition [Dube et al., 2020].

Box 1

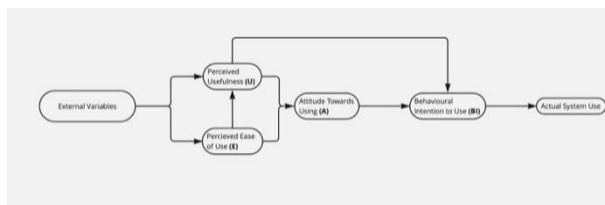


Figure 1
Technology Acceptance Model [TAM]
[Davis et al., 1989].

Box 2

Table 1

Adoption Barriers and their context	
TOE framework Context	Adoption barrier
Organization	Management support
Organization	Preparedness
Organization	Project champion
Organization	Organizational changes needed
Organization	Changing peoples minds, organization structure, strategic vision
Organization	Size
Organization	Access to financial resources
Organization	Hesitant when it comes to AI adoption
Organization	Requires employees with specific digital skills
Technology Environment	Infrastructure
Environment	Competition
Environment	External IT support
Environment	Government financing
Environment	IT skills
Environment	People in favor of adopting vs people against adopting

Box 3

Table 2

Integrative Review of Technology Adoption Models and Methods.

Cite	Cited Methods	Conclusions/Contributions
Dube, T., Van Eck, R., & Zuva, T. [2020].	Comprehensive reviews	The concept of an integrated model is endorsed by existing frameworks and hypotheses of innovation, which are slight significant in clarifying technological acceptance for the new technologies
Omriani, N., Rejeb, N., Maalouli, A., Dabić, M., & Kraus, S. [2022]	Descriptive and multivariate analysis techniques and ordered logit regression	The concept of an integrated model is endorsed by existing frameworks and hypotheses of innovation, which are slight significant in clarifying technological acceptance for the new technologies
Omriani, N., Rejeb, N., Maalouli, A., Dabić, M., & Kraus, S. [2022]	Descriptive and multivariate analysis techniques and ordered logit regression	The concept of an integrated model is endorsed by existing frameworks and hypotheses of innovation, which are slight significant in clarifying technological acceptance for the new technologies
Hendricks, S., & Mwapwele, S. D. [2024]	Qualitative research method Thematic analysis"	Although there are benefits to e-commerce adoption, if the management of organisations or the government in a developing country does not believe that e-commerce will be valuable and beneficial to them, then they may decide not to adopt it and thus cannot realise any of its benefits. Presenting a novel model of technology adoption that departs from TOE by adding the customer trust factor and performance factor
Anayat, S., Rasool, G., & Pathania, A. [2023]	Exploratory sequential mixed-method research design, which includes both qualitative and quantitative analysis of data	Comprehensive understanding of how consumers think about and make decisions regarding AI-based voice assistants

Tongsuksai, S., Mathrani, S., & Weerasinghe, K. [2023]	Qualitative data analysis was carried out using sentiment analysis" Integrative model based on the technological, organizational, environmental, and individual dimensions Qualitative research approach Case study as the research strategy for an enriched view	Investigated the characteristics for cloud ERP adoption in SMEs based on a combined TOE and UTAUT model to provide a more holistic view
Kinkel, S., Baumgartner, M., & Cherubini, E. [2022]	International online survey Regression model using natural logarithm	Internal organizational factors provide a higher explanatory contribution to the adoption of AI technologies in production than technical production factors or conditions of the external environment Innovation capabilities and digital skills contribute to the introduction of AI technologies not only at a company's home base, but also at its foreign locations The measurement of strategic competition factors as part of a company's internal organizational capabilities
Senna, P. P., Ferreira, L. M. D., Barros, A. C., Roca, J. B., & Magalhães, V. [2022]	Structural Modelling [ISM] methodology Matrix Impact of Cross Multiplication Applied to Classification [MICMAC] analysis	Identified 14 barriers to the adoption of I4.0 technologies Focusing on environment dimension barriers could prove to be a good prioritization strategy, given that these barriers had lower degrees of dependency and higher degrees of driving power when compared to all the organizational barriers, as well as to all but one of the technological barriers It identifies the set of barriers and categorizes them into the TOE framework It provides an analysis of the interrelationships between the barriers to adopt I4.0 technologies and identification of root barriers
Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. [1989]	Empirical Study	Although ease of use is clearly important, the usefulness of the system is even more important and should not be overlooked
Olimjanovich, D., Nodirovna, M., & Ugli, M. [2024]	Literature review	Governments can support small business and private entrepreneurship growth and development by creating a supportive business environment, ensuring access to finance, encouraging training and capacity building, encouraging innovation and technology, and facilitating internationalisation. By implementing these strategies in accordance with international standards, governments can support the development of small businesses and private entrepreneurship, and contribute to the overall economic development of their countries.

Methodology

This review examines the state of the art on technology adoption models, focusing on information technology and, where possible, their applicability to Mexico or similar economies.

We conduct the initial search in autumn 2024 on Google Scholar and IEEE Xplore, using the keywords "technology adoption models" and "technology adoption barriers." We further explore recent publications from 2020 onward, concentrating on the application of these models to small and medium businesses [SMBs] or small and medium enterprises [SMEs]. Additionally, we investigate subsequent publications by the first or second authors of identified papers to uncover further advancements in the field.

We also examine authors citing papers that reference the topics of interest. The inclusion criteria for article selection include technology adoption models, technology adoption barriers, SMBs, SMEs; publications from 2020 to 2024 that either cite or are cited by the selected papers.

Despite searching for current research on technology adoption by SMBs in Mexico or Latin America, we find no relevant studies. Based on these criteria, we deem 15 articles suitable for inclusion. Table 2 references the methods used in these articles.

Conclusions

The barriers to technology adoption in SMBs are revealed to persistently affect both organizational structures and individual actors. Models at both the organizational and individual levels, alongside barriers arising from technological, organizational, and environmental contexts, are analyzed, demonstrating that no single model, framework, or theory is sufficient to fully capture the complexities of the adoption process.

It is suggested by the findings that a more comprehensive understanding of this multifaceted phenomenon is offered by integrating models from both organizational and individual perspectives.

The advantage of such an integrated approach is identified in its capacity to evaluate individual-level factors together with technological, organizational, and environmental dimensions, thereby providing a holistic view of the technology adoption process. Future research should be aimed at identifying optimal combinations of models to better explain the barriers to digital technology adoption among SMBs in Latin America and the Caribbean [LAC].

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Rodolfo Luthe conceived the original idea for the paper. Gabriela Calvario and Álvaro Parres contributed to the design of the study and participated in the writing and revision process. All authors were involved in the development of the manuscript and approved the final version.

Availability of data and materials

This study is based on a literature review; no new data were generated. All sources are properly cited in the manuscript.

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Abbreviations

List abbreviations in alphabetical order.

BI	Artificial Neural Network
SECIHTI	Consejo Nacional de Humanidades Ciencias y Tecnologías
EMDEs	Emerging Markets and Developing Economies
IS	Information Systems
IT	Information Technology
IDT	Innovation Diffusion Theory
IIEG	Institute of Economic Research of Guadalajara
IoT	Internet of Things
LAC	Latin America and the Caribbean
INEGI	National Institute of Statistics and Geography
OECD	Organisation for Economic Co-operation and Development
PEU	Perceived Ease of Use
PU	Perceived Usefulness
SMBs	Small and Medium Sized Businesses
SMB	Small Medium Business
SME	Small Medium Enterprises
TAM	Technology Acceptance Model
TOE	Technology Organization Environment
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
UTAUT	Unified Theory of Acceptance and Use of Technology
UB	Usage Behavior

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Conceptual model of the impact of public policies on industrial supply chains

Modelo conceptual del impacto de las políticas públicas en las cadenas de suministro industriales

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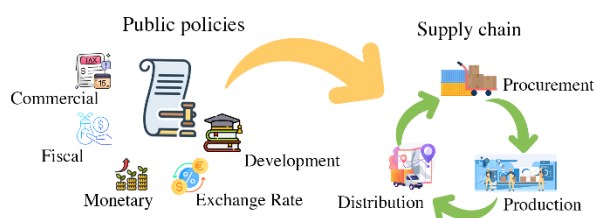


Abstract

Industrial supply chains are highly susceptible to public policy decisions; however, there remains a significant gap in understanding how these policies affect supply chain performance. This article presents a conceptual model designed to capture the dynamics of complex interactions between public policies and industrial supply chains. The conceptual model identifies five categories of public policies that influence supply chain performance: trade, fiscal, monetary, exchange rate, and development policies. These policies are linked through 21 key variables organized into seven areas. As a result, the main key variables identified are tariffs, procurement, production, and distribution. The model represents the first phase of a broader project aimed at providing a tool to simulate how public policies impact supply chain performance via system dynamics.

Resumen

Las cadenas de suministro industriales son susceptibles de las decisiones de las políticas públicas; sin embargo, existe una brecha significativa en la comprensión holística de cómo estas políticas afectan el desempeño de las cadenas. Este artículo presenta un modelo conceptual que puede utilizarse para comprender la dinámica de las interacciones complejas entre políticas públicas y cadenas de suministro industriales. El modelo conceptual identifica cinco categorías de políticas públicas que afectan el desempeño de las cadenas de suministro industriales: políticas comerciales, fiscales, monetarias, cambiarias y de desarrollo. Estas políticas se relacionan a través de 21 variables clave organizadas en siete áreas. Como resultado, se identifica que las principales variables clave son: aranceles, aprovisionamiento, producción y distribución. El modelo es la primera fase de un proyecto que busca proporcionar una herramienta para simular cómo las políticas afectan el desempeño de las cadenas de suministro con dinámica de sistemas.



Public Policies, Supply Chain, System Dynamics



Políticas Públicas, Cadena de Suministro, Dinámica de Sistemas

Area: Promotion of frontier research and basic science in all fields of knowledge

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Introduction

Supply chains facilitate the efficient flow of goods, services, and information across geographical and organizational boundaries, connecting suppliers, manufacturers, distributors, and end consumers and enabling companies to leverage the advantages of specialization, operational efficiency, and economies of scale on a global scale [Cruz, 2022; Fagan, 2024]. However, this same integration has introduced new vulnerabilities and dependencies, making supply chains highly sensitive to external disturbances, such as public policy decisions [Fagan, 2024; Pattanaik, 2023], which directly impact trade flows and create a domino effect throughout the supply chain [Feng et al., 2022].

An example of this is government decisions on tariffs, tax incentives, monetary policies, trade regulations, and technology development programs that can alter the configuration and operation of supply chains [Bednarski et al., 2025].

Specifically, tariffs are a government tax on goods imported or exported from a country [Hu et al., 2022]; they are a tool of trade policy with implications that extend beyond their direct impact on import prices [Rogers et al., 2024]. Recent empirical evidence shows that tariff measures can lead to massive reorganizations of supply chains, including the geographical relocation of production [nearshoring and reshoring] [Swenson, 2024], supplier diversification [Grossman et al., 2024], and the reconfiguration of logistics routes [Jahan & Al-Harbi, 2024].

These transformations, in turn, generate secondary effects on variables such as employment [Lepelle & Edwards, 2024], technological innovation [Zhao et al., 2024], production costs [Rogers et al., 2024] and national competitiveness [Deme & Mahmoud, 2025].

Monetary policies influence interest and exchange rates, thereby affecting investment and financing decisions along supply chains [Hernández et al., 2024]. Similarly, tax incentives and industrial development policies can change productive specialization patterns and regional competitive advantages [Kang et al., 2023].

Despite these critical interactions, traditional analytical frameworks have important limits. They often fail to reveal the systemic effects of economic policies on supply chains [Wigger, 2024]. Common approaches take a partial equilibrium perspective and focus on direct, short-term effects. They usually miss dynamic feedback, nonlinear effects, and emergent behaviors typical of these complex systems.

One methodology for analyzing complex systems is system dynamics, which was developed by Jay Forrester at the Massachusetts Institute of Technology [MIT] in the 1950s. It is based on systems thinking and provides conceptual and technical tools for modeling, simulating, and understanding the behavior of complex systems characterized by multiple interrelated variables, feedback loops, and nonlinear behavior [De Silva et al., 2024; Forrester, 1968].

The application of system dynamics to supply chain analysis has, as a result, demonstrated its ability to capture phenomena that escape traditional approaches, such as the effect of amplifying demand variability along the chain and the dynamics of accumulation and inventories over time [Azizsafaei et al., 2022; Duan et al., 2023; Guzzo et al., 2022; Vázquez-Serrano & Peimbert-García, 2020].

The methodology allows the integration of variables across different levels of aggregation [from operational decisions to macroeconomic indicators] and time horizons [from immediate responses to long-term structural transformations] [Paine, 2022; Zanker & Bureš, 2022]. This capacity for integration is fundamental to understanding how economic policies, which are typically formulated at the macro level, translate into specific effects at the level of individual companies and particular supply chains.

For the above reasons, a conceptual model using systems dynamics is designed to analyze and understand the systemic impact of public policies on industrial supply chains, identifying causal relationships, feedback loops, and dynamic behavior patterns that emerge from these complex interactions.

Methodology

The research adopts a mixed-methods approach that combines a systematic literature review conducted with the PRISMA 2020 protocol [Preferred Reporting Items for Systematic reviews and Meta-Analyses] [Page et al., 2022] with the development of a conceptual model under the systems dynamics methodology [Forrester, 1968]. This approach allows the integration of theoretical and empirical evidence from multiple sources to develop a robust conceptual model.

Following the PRISMA 2020 guidelines, the research question was established as follows: which public policies have been identified as critical determinants of supply chain performance? What are the key variables that reflect the effects of public policies across supply chains?

Searches were conducted in Scopus [Elsevier], Web of Science [Clarivate Analytics], ProQuest Business Collection, EBSCOhost Business Source Premier, ScienceDirect, and Emerald Insight for articles published in the last 20 years [2005–2025] to capture both established theoretical developments and emerging trends in the field. The search equation [["economic policy" OR "fiscal policy" OR "monetary policy" OR "trade policy" OR "tariff" OR "tax incentive" OR "government intervention" OR "public policy"] AND ["supply chain" OR "global supply network"] AND ["impact" OR "effect" OR "influence" OR "causal" OR "dynamic" OR "system" OR "model" OR "framework"]] was used in the title and keywords. Filters such as those published in English and Spanish were applied.

The following were also considered inclusion criteria:

- Studies examining causal relationships between economic policies and supply chain variables
- Research using conceptual frameworks or theoretical models to explain these relationships
- Quantitative or qualitative empirical studies with evidence on policy effects
- Research incorporating a systems perspective or dynamic approaches
- Publications in indexed journals with a peer-review process.

Exclusion criteria:

- Studies focused exclusively on operational optimization without policy considerations
- Single-case studies without theoretical generalization
- Opinion pieces or editorials without empirical support
- Studies with identified significant methodological limitations
- Duplicates.

A systematic search of six specialized academic databases yielded 1,247 records potentially relevant to answering the research questions.

Following the PRISMA 2020 protocol, a rigorous selection process was implemented in four sequential stages, which are detailed in Figure 1.

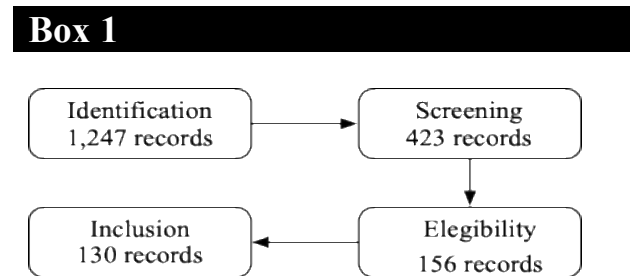


Figure 1

PRISMA flowchart of the study selection process for systematic review

Source The Authors

During the screening phase, the titles and abstracts of all identified records were evaluated via preliminary inclusion and exclusion criteria. This process resulted in the selection of 423 studies for further evaluation, excluding 824 records that were outside the thematic scope or did not meet the basic relevance criteria. The eligibility assessment involved a full-text review of the 156 preselected studies for potential inclusion in the synthesis.

At this stage, more specific criteria related to methodological quality, thematic relevance, and the availability of information pertinent to the research questions were applied. As a result, only 130 studies met all the criteria established in the protocol during the inclusion phase. These studies constitute the empirical basis for identifying critical public policies and key variables for studying their effects on supply chains.

The 130 included studies cover the period 2005–2025, with 65% concentrated in the last decade [2015–2025], reflecting the growing interest in the intersection between public policy and supply chain management.

The countries with the highest numbers of documents are China [32.62%], the United States [19.25%], and the United Kingdom [9.15%]. Other relevant countries include India [7.63%], Iran [4.69%], Australia [4.50%], Canada [4.03%], France [3.71%], and Italy [3.60%].

The key variables were identified using criteria of frequency [mentioned in at least 25% of the selected studies], theoretical centrality [acting as connecting nodes in multiple relationships], and causal relevance [variables with solid theoretical support and significant empirical evidence].

Stella Architect® version 3.8.1 was used for the construction, visualization, and analysis of the causal loop diagram. Additionally, cycle-detection algorithms for directed graphs were used to systematically identify all the feedback loops in the diagram [Rajah & Kopainsky, 2025]. Each variable exhibits positive [+] or negative [-] polarity in its causal relationships.

In a positive polarity relationship, if variable A increases, then variable B also increases; if A decreases, then B also decreases. Conversely, in a negative polarity relationship, if A increases, then B decreases; if A decreases, then B increases. Loops form when there is at least one chain of three or more variables that sequentially influence each other. Two types are identified according to their systemic behavior: first, reinforcing loops [R], which amplify system tendencies, generating exponential growth or decline; second, balancing loops [B], which counteract changes and seek to stabilize the system toward a point of equilibrium [Forrester, 1968].

Finally, whether the identified variables and causal relationships are consistent and congruent with the system dynamics was reviewed via tests of loop polarity consistency to verify that balance loops have an even number of negative relationships, completeness tests to ensure that all key variables are connected, and parsimony tests to eliminate redundant relationships [Gori et al., 2024].

Results

The analysis of the 130 included articles identified five public policies that impact supply chains, as summarized in Table 1. Each entry includes the percentage of studies in which the policy was identified [%E], the variable to be included, and the objective.

Box 2

Table 1

Categorization of identified policies

Policy - [%E]	Variable	Objective
Commercial 89%	Tariffs, Protectionist Policies	Domestic Industry Protection, Commercial Regulation
Fiscal 74%	Fiscal Incentives	Stimulation of Sectoral Economic Activity
Monetary 67%	Interest Rate	Inflation Control, Macroeconomic Stability
Exchange rate 71%	Exchange Rate	International Competitiveness
Development 58%	Educational Programs	Development of Qualified Human Capital and Innovation

Trade policies have the greatest documented impact on supply chains. These policies have immediate effects on import flows, medium-term effects on supplier reconfiguration, and long-term effects on the geographic location of production.

The literature shows that these policies generate complex systemic effects, including both the protection of domestic industries and negative externalities in sectors dependent on imported inputs [Nguyen & Dang, 2024; Suhaime et al., 2024].

Sector-specific tax incentives [R&D, exports, technology investment] act as catalysts for supply chain reconfiguration, influencing location, investment, and vertical integration decisions [Nguyen & Dang, 2024].

Fluctuations in interest rates affect working capital costs, reduce investment in supply chain improvements and innovations, as well as long-term investments, and impact consumer demand [Zhi et al., 2024].

Exchange rate policies [identified in 71% of the studies] introduce volatility and uncertainty that can affect prices, cost structures, and overall financial performance, thereby impacting export competitiveness, import costs, and procurement decisions [Ersahin et al., 2024; Li & Cheng, 2024].

Development policies [identified in 58% of the studies] align academic outcomes with industry needs, thereby improving graduate employability and contributing to economic growth, fostering partnerships between academia and industry, and incorporating innovative teaching methods [Austin & Malka, 2023; Daigle et al., 2025].

The content analysis of the selected articles identified twenty-one key variables; Appendix 1 shows the cause-and-effect relationships. These variables were organized into seven areas: supply chain [production costs, procurement, production, distribution], trade [tariffs, foreign trade, imports, exports], investment [new markets, innovation and technology, innovative strategies, country competitiveness, foreign direct investment], macroeconomics [inflation, exchange rate, interest rate, economy, domestic consumption, employment], and public policies [tax incentives, educational programs]. A total of 502 loops were identified; one balancing loop and one feedback loop were selected to describe the causal relationships between them. Under the principle of Methodological Parsimony, including all loops violates this principle.

Loop B5 [Figure 2] captures the regulation of trade competitiveness through the dynamic interactions among tariffs, production costs, exports, and foreign trade. Counteracting the destabilizing effects of tariff policies, when higher tariffs are implemented [+], they initially generate a reduction in imports that contributes to improving the foreign trade balance [+]. However, these tariffs simultaneously increase the production costs [+] of companies that depend on imported inputs, which deteriorates their international competitiveness, reduces exports [-], and creates a compensatory effect that attempts to improve foreign trade [-].

This limits the effectiveness of tariff policies and pushes the system toward an equilibrium in which trade protection is balanced with the need to maintain international competitiveness, explaining why economies tend to find "optimal" tariff levels that balance these opposing effects rather than adopting extreme positions of free trade or absolute protectionism.

Box 3

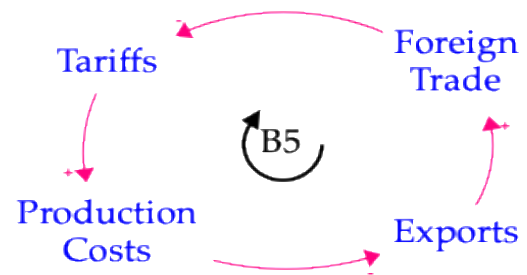
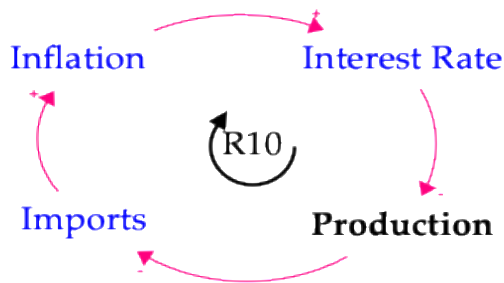


Figure 2

The R10 loop [Figure 3] illustrates the tension between monetary policy, inflation control, and economic stimulus, operating through a cycle that connects interest rate decisions with production and import dynamics. Restrictive monetary policies trigger a sequence of effects that eventually lead to their relaxation.

When monetary authorities raise interest rates [-] to control inflationary pressures, they improve competitiveness and reduce production costs, thereby stimulating productive activity [+]. This production growth generates greater demand for imported inputs [+], especially in globally integrated economies where supply chains depend on external components, creating pressures on the trade balance and the exchange rate that eventually induce a reduction in inflation [-], which again leads to a reduction in interest rates [-] to maintain competitiveness.

Successful restrictive monetary policies [which manage to control inflation] create the conditions for their own relaxation by stimulating productive growth and import demand, illustrating how open economies face a permanent challenge between price stability, productive growth and external equilibrium, where the effectiveness of a contractionary monetary policy generates endogenous dynamics that eventually push toward its reversal, explaining the recurring cycles of monetary tightening and relaxation observed in modern economies.

Box 4**Figure 3**

Loop R10: interest rate, inflation, production, imports

Source The Authors

Conclusions

This research develops a conceptual model that reflects the systemic and complex nature of interactions between public policies and industrial supply chains, providing evidence for causal mechanisms that transcend traditional sectoral analysis.

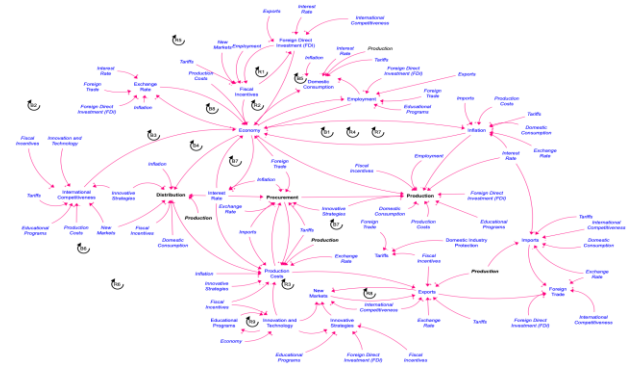
The resulting conceptual model, constructed from the synthesis of 130 articles selected via the PRISMA 2020 protocol, identified five policy categories most frequently referenced in the literature. These policies operate through twenty-one key variables in the conceptual model, developed with a systemic perspective that captures dynamic interdependencies. This confirms that industrial supply chains function as complex systems derived from the interactions among their components rather than from individual characteristics.

Multiple feedback loops that generate nonlinear systemic behaviors have been identified. Detailed analysis of specific loops, such as Loop B5 [protectionist policies where tariffs simultaneously protect industries and erode export competitiveness] and Loop R10 [which shows how successful restrictive monetary policies create conditions for their own relaxation], demonstrates that economic systems contain endogenous self-regulating mechanisms that limit the effectiveness of extreme interventions and push them toward complex dynamic equilibria.

The model captures key variables for the industrial sector, including targeted policies, to understand sector dynamics.

Future work includes developing simulation models that incorporate the causal mechanisms identified in the conceptual model and enable scenario simulation and quantitative sensitivity analysis.

Future work should also include extending the model to an international comparative analysis that examines how differences in institutional contexts, levels of economic development, and degrees of international integration modify the identified causal relationships.

Annexes**Annexes 1****Declarations****Conflict of interest**

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author Contributions

Bocanegra-Villegas, Laura Valentina: The author contributed to the writing, project conceptualization, and research development of the manuscript.

Sánchez-Ramírez, Cuauhtemoc: The author contributed to institutional coordination, validation of results, and the final correction and editing of the manuscript.

Alor-Hernández, Giner: The author contributed to institutional coordination, validation of results, and the final correction and editing of the manuscript.

Availability of data and materials

Available upon request from the author.

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Abbreviations

PRISMA 2020	Preferred Reporting Items for Systematic Reviews and Meta-Analyses.
%E	Percentage of Studies in Which the Public Policy Was Identified

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Design and Implementation of a Hyperconverged Solution with Advanced Virtualization Technology

Diseño E Implementación De Solución Hiperconvergente Con Tecnología De Virtualización Avanzada

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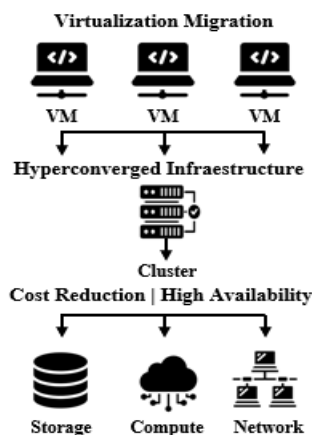
Field: Technological sciences

Discipline: Computer technology

Subdiscipline: Computer architecture

Abstract

This study analyzes the existing infrastructure of the Potosino Institute of Scientific and Technological Research [IPICYT] and the migration from the VMware system to Proxmox VE, aiming to reduce costs and enhance technological management. A hyperconverged cluster was implemented, integrating storage, processing, and networking into a unified environment, optimizing interoperability and resource administration. The research was conducted at the National Supercomputing Center [CNS], assessing the compatibility between both systems and validating the effectiveness of the integration. The results demonstrate an improvement in availability and failure recovery, strengthening the operational continuity of the CNS. Tests confirmed the proper functioning of the cluster, consolidating an efficient and adaptable infrastructure tailored to the needs of IPICYT.



Hyper-Converged Infrastructure [HCI]; Virtualization; Hyperconvergence

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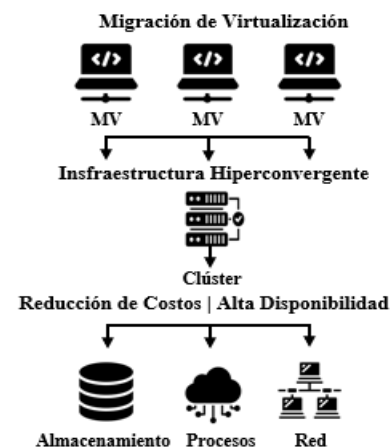
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Resumen

Este estudio analiza la infraestructura existente del Instituto Potosino de Investigación Científica y Tecnológica [IPICYT] y la migración del sistema VMware a Proxmox VE, con el objetivo de reducir costos y mejorar la gestión tecnológica. Se implementó un clúster hiperconvergente, integrando almacenamiento, procesamiento y red en un entorno unificado, optimizando la interoperabilidad y administración de recursos. La investigación se llevó a cabo en el Centro Nacional de Supercómputo [CNS], evaluando la compatibilidad entre ambos sistemas y validando la eficacia de la integración. Los resultados demuestran una mejora en la disponibilidad y recuperación ante fallos, fortaleciendo la continuidad operativa del CNS. Se realizaron pruebas que confirmaron el correcto funcionamiento del clúster, consolidando una infraestructura eficiente y adaptable a las necesidades del IPICYT.



Infraestructura hiperconvergente [HCI]; Virtualización; Hiperconvergencia

Area: Promotion of frontier research and basic science in all fields of knowledge

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Introduction

Currently, digital transformation and the growing demand for technological resources have driven the need to implement innovative solutions to optimize technological infrastructure [Eugenio Villar, 2023]. A Hyper-Converged Infrastructure [HCI] is an architectural model that combines the three fundamental pillars of a traditional data center: processing, storage, and networking. This model addresses various needs and problems related to the management, scalability, and efficiency of technological resources in diverse environments, tackling challenges of complexity, resilience, costs, and flexibility.

Thus, it provides a modern solution that improves operational efficiency and prepares organizations to face future technological demands, while also allowing compatibility with new cloud-based technological solutions.

The Centro Nacional de Supercómputo [hereinafter, CNS] provides customized solutions to meet technological demand in its role as a Data Center. It has a wide variety of technologies, as well as a logical and physical architecture that allows it to meet the objectives established by the institution in each of the projects in which it participates. However, as technology advances and the market diversifies, multiple challenges arise that complicate the continuous operability of the Data Center. One of the main obstacles is the high costs associated with virtualization solutions, which allow for adequate use of technological resources. Previously, this type of software was commercialized under business models different from those prevailing in the market today.

This situation has hindered the correct functioning of the systems, forcing the CNS to adapt to new technological demands, which is not always the best alternative to guarantee efficient operation. This adaptability limits the flexibility of systems to integrate with new solutions and interferes with projected growth.

In this case, the situation with VMware reflects this problem. The platform's current business model is no longer a viable solution [Perconti, 2021; Nutanix, 2024]. Although its software licenses are permanent, they no longer include technical support, which represents a considerable disadvantage.

Previously, licenses were managed per physical host and two processors, allowing unlimited virtual machines to be licensed per node. However, this has changed, and licensing is now done under a subscription scheme based on the number of logical cores. This has generated incompatibilities with current SKUs, and the costs to maintain system operation have increased significantly, becoming unaffordable for the CNS.

Currently, the CNS manages approximately 560 virtual machines, considering only the project on which this project is based. Given this situation, the implementation of free solutions such as Proxmox, together with a hyperconvergence environment, is being evaluated. This strategy aims to simplify and optimize IT infrastructure by integrating key components, such as storage, computing, and networking, into a single platform. The above seeks to facilitate IT management, reduce costs, and improve scalability, aligning with one of the fundamental principles of the institute as part of the Administración Pública Federal [hereinafter APF], according to the "Acuerdo por el que se emiten las políticas y disposiciones para impulsar el uso y aprovechamiento de la informática, el gobierno digital, las tecnologías de la información y comunicación, y la seguridad de la información en la Administración Pública Federal" published in the Diario Oficial de la Federación [hereinafter DOF] [Latam, 2023] dated September 6, 2021, which seeks "The implementation of new technological solutions based on free software for the better operation of systems prioritizes the use of free software as part of the republican austerity measure contemplated in the Ley Federal de Austeridad Republicana and the Ley General de Mejora Regulatoria, which aim to strengthen the use of free software, open standards, promote the development of institutional applications with public utility, achieve autonomy, sovereignty and technological independence within the APF, consolidate a robust and homogeneous technological base in State Institutions, as well as achieve greater efficiency based on the reduction of times and costs in contracting processes in matters of information and communication technologies, discarding those products or services that are not strictly indispensable for the functioning and operation of each institution."

Research Objective

To design and implement a novel hyperconverged cluster infrastructure that efficiently integrates storage, processing, and networking services into a unified environment. The proposed solution is presented as an original contribution to the field of technological infrastructure, by establishing a scalable, resilient, and easily manageable platform, adapted to the dynamic needs of modern organizations

Specific Objectives

To ensure compatibility between different operational environments through a software-defined architecture that facilitates centralized administration, optimizes system performance, and reduces operational complexity.

To successfully migrate model virtual machines, allowing necessary tests to be executed on the new hypervisor.

To implement a solution that fits the needs of the CNS, facilitating the management of logical infrastructure and improving efficiency in terms of time and costs.

To establish a solid solution that is a viable alternative to the subscription-based business models of the CNS's current providers [Red Hat, 2023; Red Hat, 2024; HPE, 2024].

To demonstrate the reliability of free software alternatives in the Data Center, as an efficient and continuous option for the operability of the projects in which the CNS participates.

Box 1

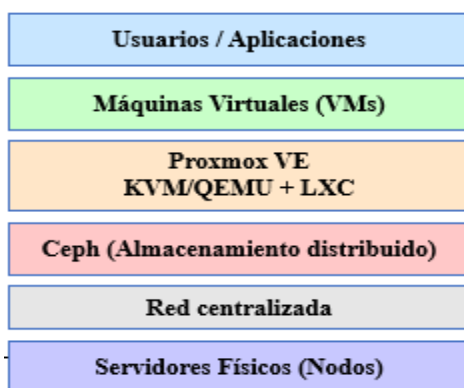


Figure 1
Hyperconverged Cluster Architecture

Box 2

Table 1

Comparison between VMware and Proxmox VE

Critero	VMware	Proxmox VE	Observaciones
Licencia	Por Cores	Libre	Reduce gastos
Soporte	Contrato	Opcional	Comunitario
Almacenaje	SAN/NAS	Ceph	No complejo
Disponible	Avanzado	Básico	Resilente

Methodology

Virtualization is defined as a technology that creates virtual representations of servers, storage, networks, and other physical machines, from a pool of physical system resources [IBM, 2024; AWS, 2024; HPE, 2024]. Allowing the implementation of this concept achieves more efficient use of physical hardware, to run multiple operating systems on the same hardware system at the same time.

To implement virtualization, software called a hypervisor is necessary, which creates an abstraction layer over the physical equipment's hardware, allowing the hardware elements of a single computer [processors, memory, storage, and more] to be divided into multiple simulated, different, and secure environments, commonly called virtual machines [VM] [IBM, 2024; Red Hat, 2023]. Each virtual machine runs its own operating system and behaves as an independent computer, although it runs on only a portion of the existing underlying computer hardware. [IBM, 2024] [AWS, 2024]. For this, virtual machines are used, which are a good option for testing new applications or configuring a production environment. A virtual machine can also be run for a single purpose, such as supplying resources for a specific process.

Hyperconverged Infrastructure [HCI] is designed for companies and organizations seeking a cost-effective, flexible, and agile infrastructure that can be managed with fewer specialists. [Syneto, 2024] This type of technology is moving closer and closer to a private or hybrid cloud as it is a modern and software-defined infrastructure that is easy and quick to deploy and manage, allowing self-provisioning and portability for the strategic placement of workloads, as it starts from the bottom and grows incrementally. [Intel, 2024].

A type 2 hypervisor is also known as a hosted hypervisor and runs on a conventional operating system as a software layer or an application. Its operation consists of extracting the guest operating systems from the host. The virtual machine resources are scheduled on the latter and run on the hardware.

These hypervisors are ideal for individual users who want to run multiple operating systems on a personal computer. Some examples are VMware Workstation and Oracle Virtualbox. However, this type of hypervisor must access computing, memory, and network resources through the host operating system, which introduces latency problems that can affect performance.

It also presents potential security risks if an attacker compromises the host operating system because they could manipulate any guest operating system running on the type 2 hypervisor, but it is very useful for personal use or for professionals who need applications only available on other software platforms. [IBM, 2024]. Proxmox Virtual Environment [Proxmox VE] [Soltecsis, 2024] is an open-source, enterprise-level hyperconverged virtualization solution [Intel, 2024; Syneto, 2024; Nutanix, 2024], that integrates virtualization through KVM/QEMU, LXC Containers, and Ceph storage on a single platform with low cost of ownership, with professional support and the possibility of obtaining official training. [Soltecsis, 2024].

High-availability infrastructure depends on the detection and elimination of single points of failure that could increase system downtime and prevent companies from achieving their performance objectives.

Single points of failure are aspects of the infrastructure that could disconnect the entire system, and there can be many of them in complex systems. It incorporates the principles of each aspect of the continuity plan, such as monitoring and automation. This allows the entire system to be resistant to any type of failure, from local and specific ones to those caused by general power outages. Furthermore, it allows it to remain running even during scheduled maintenance periods or other interruptions. [Red Hat, ¿Qué es y cómo funciona la alta disponibilidad?, 2022]

Results

By implementing a hyperconverged cluster that integrated the management of storage, processing, and networking from a single environment, compatibility between different work environments is ensured, and an efficient and easily manageable infrastructure is provided [Eugenio Villar, 2023].

After its implementation, the cluster made it easy to identify the benefits of the features it possesses and was configured with; for example, the JBOD disk format, by not having a complicated configuration, allows using disks of different sizes and characteristics without the need to configure them in a specific structure; disks can be added to the system independently without compatibility problems with the rest of the array [Pineda, 2024; HPE, 2024].

The existing virtual machines in VMware that were migrated to the new Proxmox VE cluster were successful. This process allowed verification of operational continuity and data integrity during and after the migration. During the migrations, the continuous availability of the virtual machines was verified through real-time monitoring and connectivity tests. The processing, network, and storage levels in the cluster were verified, obtaining results that demonstrated its capacity to handle critical workloads efficiently.

The implemented cluster offers centralized administration, scalability, and flexibility, which facilitates the adoption of a more robust and versatile work environment for the institute.

The implementation of the hyperconverged cluster generates significant benefits both at the technical and organizational levels; the centralized management of resources from Proxmox VE reduces the complexity in handling infrastructure, allowing focus on specific details such as the administration and configuration of the network and connectivity since it is a shared environment and a misconfiguration would mean a delay in implementation.

The solution allowed the integration and management of resources effectively between the existing VMware systems and Proxmox VE, facilitating interoperability in the institute's technological ecosystem. The consolidation of storage, networking, and processing into a single environment improved the utilization of physical and virtual resources, resulting in more efficient use of the infrastructure. Proxmox VE proved to be a more economical alternative compared to VMware, reducing costs associated with licenses and maintenance without sacrificing key functionalities.

The cluster architecture guaranteed high availability and failure recovery capacity, improving the institute's operational continuity. The created infrastructure is aligned with the institute's current and future needs, providing a solid foundation for technological growth and innovation. The implemented hyperconverged cluster not only met the set objectives but also proved to be an effective solution for optimizing the institute's operations. Its capacity to manage storage, processing, and networking from a unified environment contributed to creating a modern, scalable, and adaptable infrastructure to the demands of a constantly evolving technological environment.

Conclusions

The implementation of a hyperconverged cluster with Proxmox VE at the CNS allowed validation of the feasibility of free software solutions as an alternative to commercial platforms. The migration of virtual machines from VMware was carried out successfully, ensuring service continuity and data integrity.

The obtained results demonstrate that the designed infrastructure offers high availability, resilience, and scalability, optimizing the utilization of technological resources and reducing operational costs [Perconti, 2021; Nutanix, 2024]. Likewise, the centralized administration of the environment simplified management processes, improving efficiency in the institute's daily operation.

The project evidenced that hyperconvergent architectures not only represent an economically viable alternative but also a robust and adaptable solution for public institutions that require reliable and long-term environments.

This experience strengthens technological sovereignty and contributes to the reduction of dependence on vendors with restrictive licensing schemes [Intel, 2024; Syneto, 2024; Red Hat, 2023].

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Olvera-González, Edgar: project design, manuscript writing, and general coordination.

Cerda-García, Jorge: methodological development, results analysis, and technical review.

Viramontes-Reyna, José: bibliographic review, documentation support, and article editing.

Alfaro-Castro, Jocelyn: migration testing implementation and hyperconvergence environment validation.

Availability of data and materials

The data and materials used in this research are available upon request to the corresponding author. No legal or technical restrictions are included for their access.

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Abbreviations

APF	Administración Pública Federal
Ceph	<i>Reliable Autonomic Distributed Object Store</i> [almacenamiento definido por software]
CNS	Centro Nacional de Supercomputo
DOF	Diario Oficial de la Federación
HCI	Hyper-Converged Infrastructure / Infraestructura Hiperconvergente
IPICYT	Instituto Potosino de Investigación Científica y Tecnológica
JBOD	Just a Bunch of Disks / Conjunto Simple de Discos
KVM	Kernel-based Virtual Machine
LXC	Linux Containers
QEMU	Quick EMUlator [emulador/virtualizador]
VM	Virtual Machine / Máquina Virtual
VMware	Virtual Machine Software [plataforma de virtualización]

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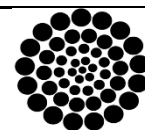
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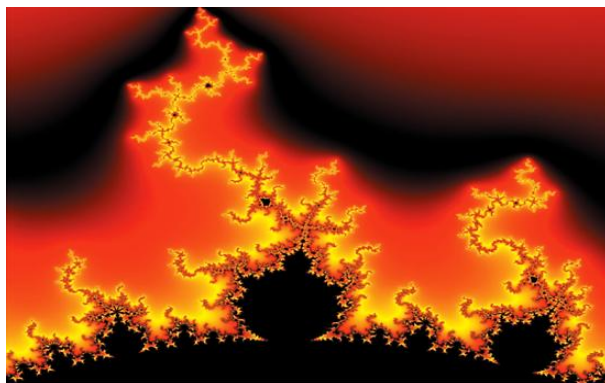


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